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The new experiment WAGASCI for water to hydrocarbon neutrino cross section measurement using the J-PARC beam

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Abstract. The T2K (Tokai-to-Kamioka) is a long baseline neutrino experiment designed to study various parameters that rule neutrino oscillations, with an intense beam of muon neutrinos. A near detector complex (ND280) is used to constrain non-oscillated flux and hence to predict the expected number of events in the far detector (Super-Kamiokande). The difference in the target material between the far (water) and near (scintillator, hydrocarbon) detectors leads to the main non-canceling systematic uncertainty for the oscillation analysis. In order to reduce this uncertainty a new water grid and scintillator detector, WAGASCI, has been proposed. The detector will be operated at the J-PARC neutrino beam line with the main physics goal to measure the charged current neutrino cross section ratio between water and hydrocarbon with a few percent accuracy. Further physics program may include high-precision measurements of different charged current neutrino interaction channels. The concept of the new detector will be covered together with the actual construction plan.

1. Introduction

The T2K (Tokai-to-Kamioka) is a long-baseline neutrino experiment in Japan with the main goal to study neutrino oscillations. In the T2K oscillation analysis flux and cross section (model) parameters are largely constrained by the near detector (ND280) measurements [1]. The systematics uncertainties on predicted number of signal events for different oscillation channels are presented in table 1 [2]. As can be seen from the table the largest one is a non-canceling uncertainty related to the cross section model and is caused by the difference in the target material between the near (hydrocarbon, CH, as the active target) and far detectors (Super-Kamiokande, Super-K, water Cherenkov detector), and also by the limited acceptance of ND280 (Super-K has 4π coverage). The new water-scintillator detector (WAGASCI, WAter-Grid-SCIintilator-Detector) is proposed to reduce this systematic error with the approach similar to the one previously used to measure the Fe to CH neutrino cross section ratio with the INGRID detector (sandwich iron-scintillator detectors + "proton" module of pure hydrocarbon) of the T2K ND280 complex [3]. The main goals of the proposed detector are:

- measurement of the charge current cross section ratio between water and scintillator targets with 3% accuracy,
- measurement of different charged current neutrino interaction channels with high-precision and large acceptance.

Table 1. Uncertainties for predicted number of signal events for different oscillation modes.

Systematics	$\nu_\mu \to \nu_e$	$\nu_\mu \to \nu_\mu$	$\overline{\nu}_\mu \to \overline{\nu}_\mu$
Flux & XSEC	3.1	2.7	3.4
Non-canceling XSEC	4.7	5.0	10.0
Super-K detector etc.	2.4	3.0	2.1
FSI+SI	2.7	4.0	3.8
Total	6.8	7.7	11.6

The new detector will be located in the ND280 detector pit and hence utilize the same neutrino beam provided by the J-PARC synchrotron. A 1.5° off-axis angle will be used which results in ν flux similar to the one of the ND280 off-axis complex (2.5 degrees), as shown in figure 1. The neutrino energy spectrum is peaked at $\simeq$0.7 GeV.

2. WAGASCI Detector Design

Figure 2 shows the basic design of the WAGASCI. There are two main elements of the detector: the central part is a neutrino interaction target which contains water and hydrocarbon, the target is surrounded by muon range detectors (MRDs). The central part consists of four alternating modules filled with water or hydrocarbon. The key element of the detector is the usage of 3D-grid structure made out of thin scintillator bars of $1000\times25\times3\ mm^3$ each (figure 2). Cells between the active bars are filled with a certain material (water or CH), this design maximizes the fraction of the target material up to 80% level and also provides good particle tracking capabilities allowing to reconstruct tracks emerging at large angles w.r.t. neutrino beam direction. The total size of the target is $1\times1\times2\ m^3$.

The muon identification and muon momenta measurements will be provided using MRDs, which have sandwich structure of alternating iron and scintillator layers. In order to estimate the direction of reconstructed tracks, reduce background from neutrino interactions in MRDs

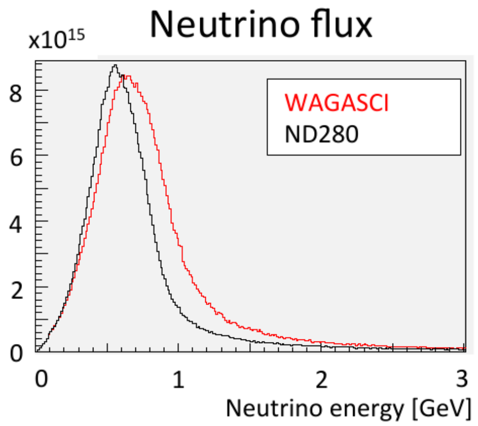


Figure 1. Expected neutrino flux at the site of WAGASCI (red line) and of the T2K off-axis near detector (black line).

and walls of the detector hall, the time of flight information between the target and muon range detectors will be utilized.

Plastic scintillator bars will be used as active elements in both target and surrounding muon range detectors. Light collection is done by utilizing WLS fibers (embedded into the grooves) that transport light to the photosensors, Hamamatsu MPPCs will be used for the latter. For WAGASCI experiment new generation of MPPCs will be used, these sensors have low dark noise rate, wider range of operation over-voltage ($\simeq$4V, allowing to increase the efficiency), and low rate of afterpulses and crorsstalk between the pixels.

It is crucial to obtain high detection efficiency with thin bars of the target area so to fulfill the requirements of the physics program. The performance of plastic scintillator bars was measured with the 600 MeV positron beam. The average light yield was found to be 10-18 p.e. and the detection efficiency was better than 99% for the whole region of scintillator with a threshold set to 1.5 p.e.

The WAGASCI detector will collect data with both polarities of T2K focusing horn system. Operation with the anti-neutrino beam will require reduction of neutrino background which is about 30% in this case. In order to provide charge-based discrimination of daughter particles it is proposed to utilize a Magnetized IroN Detector (MIND) [4] located downstream of the target (as an alternative to the downstream MRD). The MIND has a structure which consists of alternating layers of scintillator detectors and iron plates, the latter are magnetized by normal conducting aluminum coils wound on the surface of each individual plate. The sign of the particle charge is identified by the analysis of the trajectory (track curvature) in the magnetic field. The efficiency to identify correctly the charge is expected to be of 90%, which will allow to decrease the background of neutrino interactions down to 2.9% level.

3. Expected Detector Performance

The expected performance of the WAGASCI detector is studied with Monte Carlo methods. The neutrino flux and neutrino interactions inside the detector are simulated by JNUBEAM [5] and NEUT [6] respectively. Further modeling includes propagation of secondary particles through detector media (by means of GEANT4 [7] toolkit), emission of scintillation light, processes inside WLS fibers and light collection by MPPCs.

A neutrino charged current interaction in the central detector is identified by a track starting from the fiducial volume of the target and entering one of the MRDs, where the MRD is used to

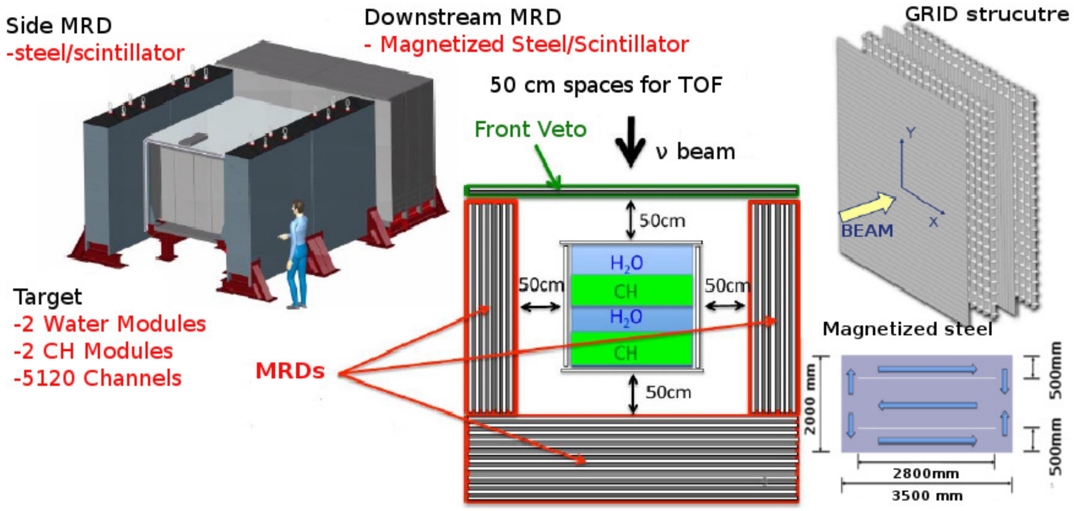
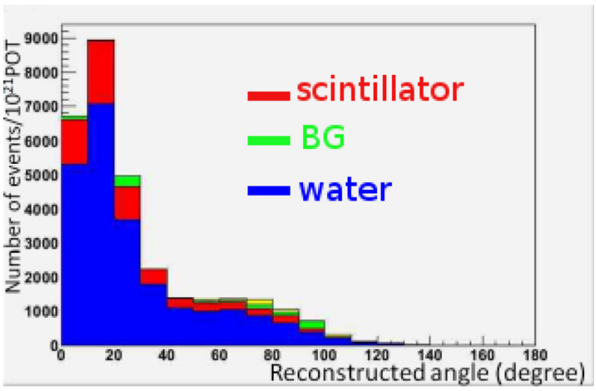
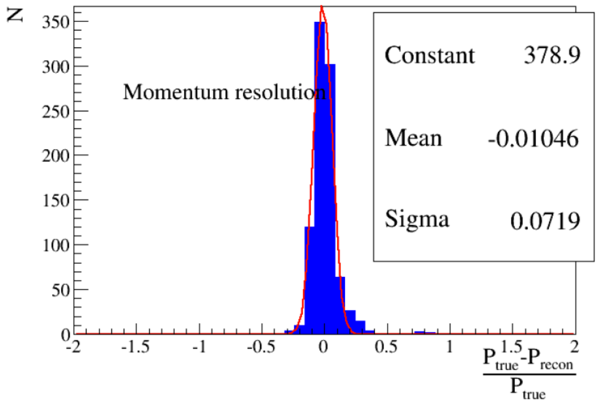


Figure 2. The basic structure of WAGASCI detector including one of the possible designs for MIND plates.

identify a long muon track. Tracks crossing the central part and the MRD are required to stop in the detector. The expected number of detected events from hydrocarbon target and water target with 10^{21} protons on target (POT) are 3×10^3 and 2.5×10^3, respectively. The purity of charged current events for hydrocarbon and water interactions is 91.0% and 75.5%, respectively. Some basic distributions for selected events are shown in figure 3.



(a)



(b)

Figure 3. (a): reconstructed angle of muon candidate for water target events that pass the selection; events split into categories based on true vertex location. (b): $\simeq$7% momentum resolution achieved for tracks stopping in MRDs.

For basic performance tests of the WAGASCI target a test experiment will be carried out. A prototype of the WAGASCI target will be installed in front of the central INGRID module of the T2K near detector to take on-axis neutrino beam data. The total size of WAGASCI prototype is $125 \times 125 \times 46$ cm^3 and the total mass is 1.2 kton. It is expected that the cross section ratio between H_2O and CH will be measured with a total uncertainty of 3 % with 1×10^{20} POT and 5 % with 2×10^{20} POT in the positive and negative (anti-neutrino beam) focusing mode, respectively, although the angular acceptance will be significantly limited w.r.t. to the full WAGASCI. The prototype will be constructed in October-December 2015.

The construction of the full WAGASCI detector will start at the end of 2015 and the physics data taking is scheduled to begin in late fall of 2016.

4. Conclusion

To reduce the systematic uncertainties for the T2K neutrino oscillation analysis and to measure different channels of charged current neutrino interactions the new experiment WAGASCI is proposed. The detector design will allow to measure the cross section ratio between water and hydrocarbon with 3% accuracy. The exact design of the detector and its components is still being finalized. The construction and installation of WAGASCI detector will start at the end of 2015 and the physics operation will start in the fall of 2016.

Acknowledgments

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